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Review Article

Nature-based solutions with sponge functions: socio-economic importance and valuation

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Abstract

This article examines the socio-economic importance and valuation of different types of wetland restoration as nature-based solutions (NBS). Wetlands, like other NBS, generate positive externalities in the form of ecosystem services, with benefits accruing to a wide range of societal beneficiaries beyond landowners. However, the implementation of wetlands and other NBS is often constrained by several barriers, including limited awareness of their socio-economic benefits. Qualitative and quantitative assessments of ecosystem services can help address this gap by providing evidence-based arguments for public communication and decision-making.

The study demonstrates such assessments using three case studies of wetlands implemented in different contexts: a rural wetland, an urban wetland, and large-scale floodplain restoration. Cost–benefit analysis is applied to illustrate how these measures can be evaluated and how their socio-economic feasibility can be communicated. In the first case study, the restoration of a natural pond with a wetland in Bratčice, Czech Republic, representing a rural wetland, the monetised benefits reach EUR 562,000 over a 25-year period and exceed costs by approximately EUR 60,000, with a payback period of 15 years. In the second case study, an urban wetland implemented as part of park revitalisation in Pilsen, Czech Republic, monetised benefits of EUR 14.2 million exceed costs by EUR 12.9 million over 25 years, resulting in a payback period of one year.

For the floodplain restoration case study in Germany, the results indicate that, even without monetising the primary flood protection function, the economic case for large-scale restoration can be substantial. Monetising only a single benefit (nutrient retention) accounts for half or more of total costs, highlighting the relevance of conservative economic valuation for supporting investment decisions in wetland restoration.

Highlights

- Wetlands are important nature-based solutions providing positive externalities;
- Results show that the monetised benefits significantly exceed the costs;
- Payback period for wetland case studies from a social perspective is 1 to 15 years;
- Socio-economic analysis offers arguments for planning and decision-making;
- Benefits in monetary terms are an important input for better communication.

Key words: benefits, cost–benefit analysis, ecosystem services, wetlands

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Introduction

In the face of climate change, there is a growing emphasis on nature restoration and resilience at the EU, national and local levels. These approaches are increasingly viewed as an efficient way to adapt to climate change, reduce risks and prevent natural disasters. The implementation of nature-based solutions (NBS) is presented as an effective environmental policy instrument for climate change mitigation and adaptation by providing multiple ecosystem services (ES) and related socio-economic benefits derived from nature (Castellar et al. 2021; Stammel et al. 2026).

The prioritisation of ES delivered by NBS varies according to the local context and the specific hydrological challenges addressed. In urban and peri-urban settings, demand typically concentrates on effective stormwater management and the attenuation of rapid runoff, accompanied by secondary benefits such as microclimate cooling, improved aesthetic quality and recreational opportunities. In rural and broader landscape contexts, the primary focus often lies on increasing water retention capacity to moderate both drought and flood impacts. Across all settings, however, the enhancement of biodiversity represents a consistently valued outcome.

A number of studies (Anderson et al. 2022; Valencia Cotera et al. 2023) show that there is a low level of knowledge about the available types and benefits of NBS and that investors often lack information about their economic feasibility. Low awareness and limited information about the positive aspects of NBS implementation result in low support from both public and private investors. However, it has been estimated that, across all types of NBS, the monetary value of the benefits is on average eight to ten times higher than the investment costs (European Commission 2022). In this context, the role of socio-economic assessment in relation to NBS is increasing as a way to monetise benefits and communicate results to stakeholders. Cost–benefit analysis (CBA) is typically used to assess and compare the costs and benefits in monetary terms and has been widely applied in the context of NBS (Claus and Rousseau 2012; Hekrle et al. 2023). It is considered a comprehensive method, as it expresses both costs and benefits in monetary units and allows for the inclusion of externalities as well as sensitivity analysis (Chelli et al. 2025). By accounting for externalities, CBA is regarded as a suitable tool for evaluating NBS and for determining whether the implementation of an intervention is economically justified (Chairat and Gheewala 2024). The results of such analysis can provide social and economic arguments for the implementation of NBS and can be an effective way to foster their implementation and planning processes.

Despite its widespread application in the evaluation of NBS, the literature highlights several important limitations of CBA. A key challenge lies in the valuation of non-market benefits, which is highly sensitive to the choice of valuation methods and value-transfer approaches; different methods may yield substantially different results and thus affect the ranking of alternative options (Boda 2018; Dennig 2018). Another critical limitation concerns the selection of the discount rate (Masur and Posner 2018), which strongly influences the temporal distribution of costs and benefits and may disadvantage long-term environmental benefits, potentially altering decision outcomes. Moreover, the application of CBA is associated with high demands on data availability, time, financial resources and expert knowledge (Vejchodská 2015; Bolinches et al. 2020).

These requirements represent a significant barrier, particularly at the municipal level and in early planning phases, where detailed inputs are often lacking. Insufficient economic expertise and limited institutional capacity can therefore increase uncertainty in the results and, in some cases, limit the suitability of CBA as a decision-support tool for public policy-making (Dehnhardt et al. 2022).

The main aim of this paper is to demonstrate how key benefits associated with NBS can be systematically identified and translated into monetary terms using available data. By doing so, the analysis aims to provide evidence-based arguments about the contribution of the assessed measures and to support the justification of public investments. The applied approach is intended not only to inform the evaluation of the presented case studies but also to offer a transferable methodological reference for future CBA applications and to inspire the implementation of similar measures in other contexts.

The paper demonstrates the applicability and added value of an extended CBA framework that explicitly incorporates different ES and applies it to selected NBS for water retention across different territorial contexts. The analysis is illustrated by two case studies from the Czech Republic and one large-scale floodplain restoration project in Germany, representing urban, rural and landscape-scale interventions.

By comparing the results across these diverse settings, the paper shows how the magnitude, structure and relative importance of costs and benefits differ depending on the type of measure, its spatial and ecological context and the assessment methods used. The findings underline the strong context dependence of CBA outcomes, with important implications for decision-making, the prioritisation of interventions and the transferability of results across territorial scales.

Preferences, ecosystem services, and economic assessment of nature-based solutions

Preferences and barriers related to NBS implementation

Although the implementation of NBS is said to be very beneficial for human and nature well-being, there appear to be many barriers that discourage potential investors from adopting the measures. There are different barriers to adopting NBS in different types of landscape, but some of them are common across all types.

Beyond individual awareness and motivation, the uptake of NBS is constrained by socio-political and institutional conditions that shape what is feasible and attractive to implement (Nelson et al. 2020; Calliari et al. 2022; Martin et al. 2025; Klusmann et al. 2026). Governance is often dispersed across sectors and scales, creating fragmented incentives and coordination problems, while established planning routines and professional norms can reproduce “grey” path-dependent trajectories that lock decision-makers into conventional infrastructure even when NBS are efficient over longer horizons (Nelson et al. 2020; Martin et al. 2025). Limited local administrative and technical capacity, including shortages of specialised expertise and knowledge brokerage, further raises transaction costs and amplifies reliance on familiar technical solutions (Vejchodská 2015; Bolinches et al. 2020; Dehnhardt et al. 2022). At the same time, economic appraisal does not remove contestation: monetary valuation of ES is uncertain and can be criticised for simplifying plural, place-based values,

and it may obscure distributional questions about who benefits and who bears costs (Saarikoski et al. 2022; Viti et al. 2022; Blouin et al. 2025). These combined uncertainties, justice considerations, and structural lock-ins help explain why favourable cost–benefit results do not automatically translate into implementation in practice (Slavíková and Raška 2019; Martin et al. 2025).

Many studies (Solheim et al. 2021; Wheeler and Lobley 2021; Duffaut et al. 2022; Stoffers et al. 2026) analysing barriers to NBS implementation agree on a "lack of knowledge", specifically regarding which measures exist, what the impacts are, and what benefits they provide. Low awareness leads both to limited support for the measures among decision-makers and, often, to support for other, less effective and efficient measures. A low level of knowledge about NBS, their functions and benefits is also one of the crucial barriers in the Czech Republic, as Krčmářová et al. (2021) and Zaňková et al. (2025) found through questionnaire surveys.

There may be some differences between the level of knowledge about possible NBS in cities and in open landscapes or agricultural land. NBS in cities are designed by architects or spatial planning experts, who are expected to have more information about possible solutions, in contrast to adaptation measures such as NBS in agricultural land, which have to be adopted by landowners or land users (who have a contract with the owner). Seeking information about NBS, its impacts, costs and benefits is supposed to be a time-consuming process for farmers and landowners. Additionally, landowners resist changes on their land, as it is the source of their income (Potočki et al. 2022).

Many authors try to refute the assumption that financial incentives are the driving force for adopting the measures (van Dijk et al. 2016). The authors studied the willingness to adopt only unsubsidised measures so that motivation would not depend on external factors such as financial compensation. According to the results, self-identity is the most important factor that should be analysed and supported. Self-identity as a driver is also very important for the implementation of NBS in other studies (Baur et al. 2016; Chen et al. 2023). According to surveys among Czech farmers, there are three main barriers that prevent them from adopting measures (Meierová and Chvátalová 2022). These are financial barriers, ownership structures and administrative barriers, which make farmers feel frustrated. Very similar results come from a survey conducted by Macháč et al. (2020), where almost none of the interviewed farmers planned to implement an adaptation or mitigation measure. The survey showed that the main barriers are administrative burdens, complicated ownership and current legislation. Financial aspects (in the form of a low level of own financial sources, low subsidies or reduced revenues) were assessed as less crucial. However, financial compensation and the reduction of bureaucracy were the most frequently chosen motivations for implementing measures.

Importance of wetlands in provision of ecosystem services in the context of climate change

There is a wide range of measures known as NBS. These measures combine green and water elements such as trees, rain gardens, retention ponds or green roofs (Castellar et al. 2021). Often, these green-blue elements are presented as substitutes for more technical measures, referred to as grey infrastructure. In practice, green-blue elements that are part of NBS are implemented in combination with grey elements, creating so-called hybrid measures (Anderson et al. 2022).

NBS, including wetlands, provide benefits from different categories of ecosystem services, which are often inseparable, so that multiple benefits are usually provided at the same time, which represents an advantage over so-called grey infrastructure measures. These nature-related benefits are referred to as ES, which can be divided into four categories: (i) provisioning services; (ii) regulating services; (iii) cultural services; and (iv) supporting services (Fig. 1). All of these services affect various aspects of human well-being. The ecosystem services concept serves as a tool for identifying, describing and quantifying benefits.

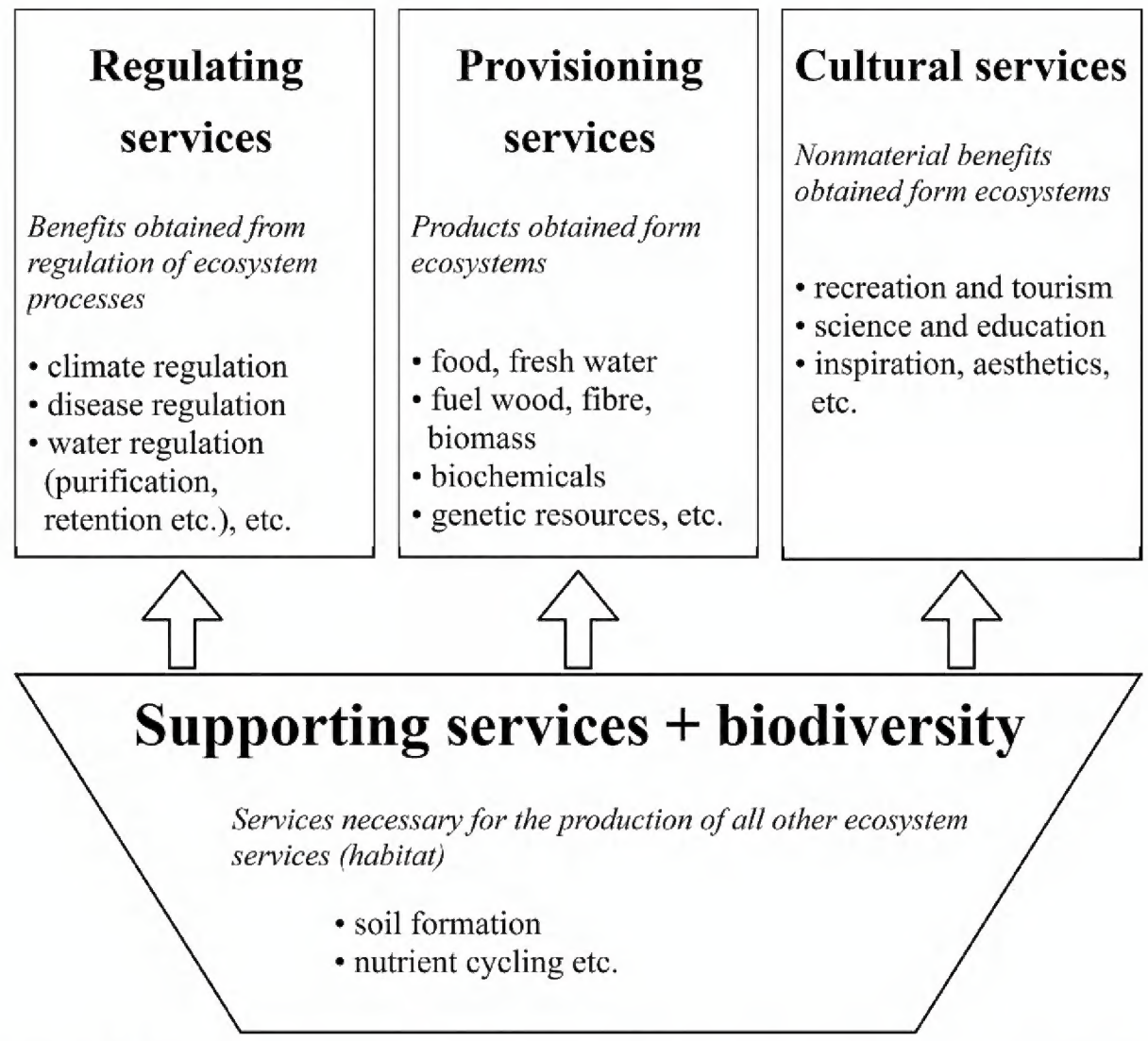
Regulating services
Benefits obtained from regulation of ecosystem processes
• climate regulation
• disease regulation
• water regulation (purification, retention etc.), etc.
Provisioning services
Products obtained form ecosystems
• food, fresh water
• fuel wood, fibre, biomass
• biochemicals
• genetic resources, etc.
Cultural services
Nonmaterial benefits obtained form ecosystems
• recreation and tourism
• science and education
• inspiration, aesthetics, etc.
Supporting services + biodiversity
Services necessary for the production of all other ecosystem services (habitat)
• soil formation
• nutrient cycling etc.

Figure 1. Classification of ecosystem services. Source: Macháč and Louda (2019).

While the ES concept has become a widely used framework for describing and categorising the benefits that humans derive from nature (Haines-Young 2023), its practical application in public administration and planning remains limited. One frequently cited reason is that the concept is perceived as abstract and difficult to operationalise, particularly for non-specialist decision-makers (Albert et al. 2019; Blouin et al. 2025). To address this gap, monetary valuation is often proposed as a means of translating ecosystem service benefits into forms that are more easily comparable with other policy-relevant considerations (Ghaley et al. 2014; Greenhalgh et al. 2017; Macháč et al. 2021).

At the same time, the monetisation of ES has been subject to extensive debate. Critics argue that monetary valuation may oversimplify complex socio-ecological relationships and inadequately reflect cultural, ethical and distributional dimensions, as well as trade-offs among competing ecosystem management objectives (Boda 2018; Ainscough et al. 2019; Saarikoski et al. 2022). Despite these limitations, ecosystem service valuation is widely regarded as a pragmatic approach for supporting environmental decision-making, particularly in contexts where NBS must be justified alongside conventional economic criteria (Dehnhardt et al. 2022). In this sense, monetary valuation is not intended

to capture the full spectrum of ecosystem values but rather to complement other forms of knowledge by helping to make societal benefits more visible in planning and policy processes (Kremer et al. 2016; Saarikoski et al. 2022).

The implementation of wetlands is increasingly discussed within the concept of NBS, both in the landscape and in the urban environment, as their implementation brings multiple socio-economic benefits and ES (Gutman 2019; García-Herrero et al. 2022). Large-scale water pollution and the loss of wetland ecosystems in the EU landscape are considered to be a consequence of extensive drainage in recent decades (Scholz 2022), resulting in a limited presence of these measures in urban and landscape settings. However, wetlands can improve water quality by capturing nutrients and filtering pollutants from discharged water (Keesstra et al. 2018; Zak et al. 2026).

In land management, wetlands also have a significant positive effect on flood risk management, reducing flood risk, improving air quality, water supply and soil protection, and they can also serve as habitats for species, thereby improving biodiversity. In addition, there are non-environmental benefits, such as economic and social benefits (energy and water cost savings, aesthetic value and recreation), which are also important (Macháč and Louda 2019).

Economic assessment of NBS

Low awareness of the beneficial aspects of NBS is a crucial barrier to its implementation (Kabisch et al. 2016; Sarabi et al. 2020). To address this, different strategies can be used to increase awareness and to convince landowners or potential investors.

CBA is an effective approach to monetise and subsequently compare the costs and benefits associated with NBS, making these values more understandable to the general public. This can facilitate decision-making processes, improve communication, increase acceptance and participation, and strengthen the enforceability of NBS (Chelli et al. 2025).

Within CBA, the assessment goes beyond the consideration of private financial benefits and costs; it also encompasses socio-economic ones that affect society as a whole. While societal costs and benefits are often difficult to quantify in monetary terms, they play a crucial role in human well-being and overall quality of life. These values are typically derived from public preferences, either through relevant market prices or through willingness to pay for specific services or goods. However, only certain socio-economic benefits and ES, not all, can usually be quantified using these methods (Macháč et al. 2019).

The aim of CBA is to assess the costs and benefits associated with the implementation and maintenance of measures and then to compare them over a specified time horizon in terms of their net present value (NPV). The individual steps of CBA are shown in Fig. 2 and are further described, for example, by Macháč et al. (2019) and Hekrle et al. (2023).

The most important basic step in the CBA assessment is to identify the measure, including the territorial scope of the impacts, because many measures are associated with local social benefits (e.g. climate regulation), benefits that affect whole human settlements (e.g. recreation) and global benefits (e.g. greenhouse gas absorption). The next step is to identify and qualitatively describe the costs and benefits of the measure. This step can be used to focus on a group

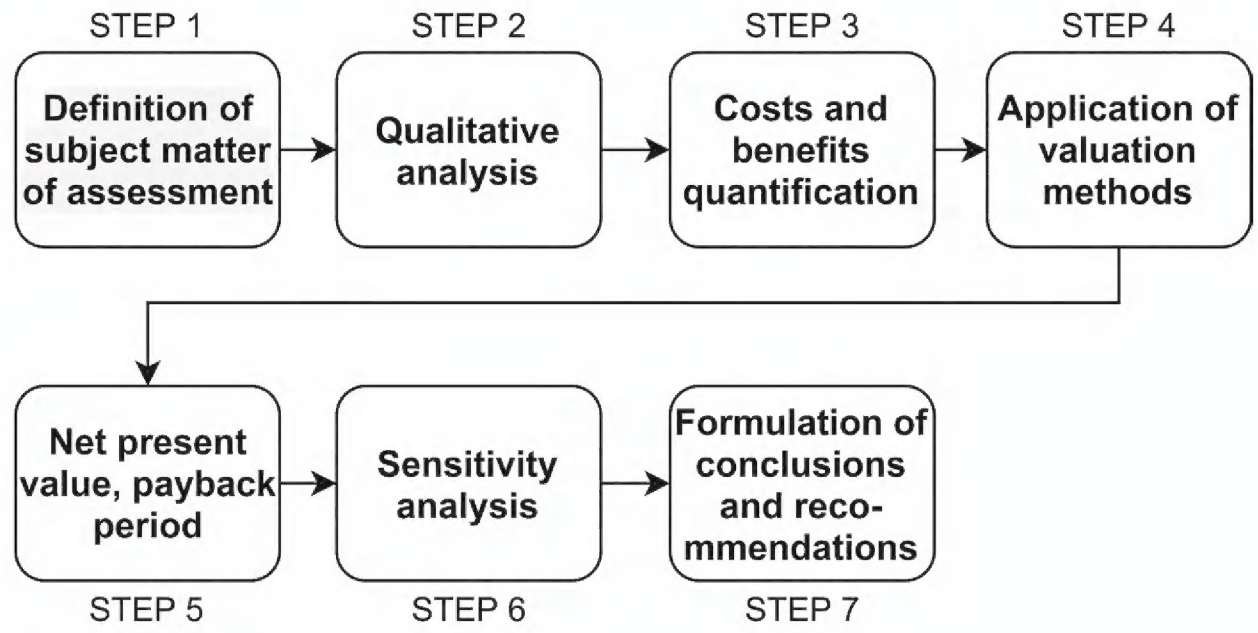

Figure 2. CBA steps. Source: authors.

of the most important benefits when expressing their monetary value. It is then necessary to quantify the level of benefits. For this purpose, biophysical units can be used, such as the number of substances captured, the amount of water retained or the amount of carbon stored. As obtaining these values is time- and cost-consuming, value transfer from accessible databases or literature research may be a more suitable solution. Most ES take the form of non-marketed benefits without visible monetary values. Nevertheless, there are ways to express them in monetary units using various environmental economic methods.

The cost side of the CBA includes mainly investment and maintenance costs, administrative costs and costs of negative externalities. These costs are assumed to be social investments that need to be incurred. The benefit side of CBA consists of direct positive financial impacts and socio-economic benefits, which represent a very important and non-negligible part of the assessment.

The next step is to select and apply assessment methods that are suitable for benefit monetisation (Table 1), e.g. market price method, cost substitution method, discrete choice experiment, hedonic price method, avoided cost method and benefit transfer. As a result, costs and benefits are expressed in monetary units in the next step of the analysis, with the calculation of the net present value. The outcome is the total net benefit of the measure from a society's perspective, and it is also possible to express the payback period and the feasibility of the measure over the time horizon, i.e. when the point at which benefits exceed costs.

This CBA approach was used to assess two wetlands in the Czech Republic – a rural wetland in Bratčice and an urban wetland in Pilsen – and the floodplain forests of the Middle Elbe in Germany.

Methods and data

Case study Bratčice (rural wetland)

The case study in the municipality of Bratčice represents a rural landscape type, where the restoration of a natural pond with a wetland was motivated by respect for the most important ES in this landscape type – aesthetics, recreation and rainwater management. Before the restoration in 2019, there was an unused fire reservoir tank full of sediments and foul-smelling water. Thanks to the revitalisation, the area became a natural pond with wooden footbridges, a wetland, and equipment supporting leisure-time activities, such as play elements (Fig. 3).

Table 1. Suitable assessment method for individual ES and other relevant benefits provided by wetlands.

Ecosystem service/benefit provided	Suitable valuation method
Regulating services	
Runoff regulation	Market prices (saving of costs for wastewater treatment)
Water quality (reduction of N and P)	Mitigation costs; costs of alternative measures (cost saving on treatment of consumed water)
Flood risk reduction	Market prices (as per damages); mitigation costs
Air quality (absorption of NO_2, SO_2, O_3 and PM_{10})	Mitigation costs; costs of alternative measures (retention of pollutants from the air: dust particles – reduction of wind erosion, nitrogen oxides, sulphur oxides and ozone)
Soil erosion	Costs of alternative measures (cost saving on purchase of lost soil and cost saving on nutrient replacement and removal of sediment from watercourses)
CO_2 sequestration	Mitigation costs; costs of alternative measures; market price of CO_2 permits
Cultural services	
Recreation benefits	Choice experiment method; travel costs method
Aesthetic value	Stated preferences method: choice experiment; willingness to pay
Production services	
Biomass production	Market price method (biomass purchase price after subtracting necessary costs of transport, and so on)
Crop production	Market price method
Water supply	Market prices (saving of costs for pumping water from other sources/costs of other water retention methods)
Others	
Biodiversity increase	Choice experiment method
Value of properties in the neighbourhood	Market prices (increase in prices due to improved quality of greenery and public spaces)

Source: own analysis based on Macháč et al. (2019).

Rainwater from both residential rooftops and public areas covering over 2.5 hectares is diverted to a pre-treatment wetland before flowing into a semi-natural pond and wetland, replacing the original sewer discharge system. The pond and wetland capacity has been increased, and the appearance of the area and its surroundings has been improved. Water from the pond is also pumped to an accumulation tank and then used for regular irrigation of greenery in the area. The area is used for cultural and social activities of the residents and by firemen, who use the revitalised pond for training and competitions.

This case study illustrates how the conversion of a degraded fire-fighting reservoir into a near-natural pond with wetland features can deliver multiple benefits at the municipal level. The economic assessment therefore focuses on capturing the combined value of improved rainwater retention and management in the central part of the municipality, together with recreational and amenity benefits resulting from the revitalisation of the site.

Case study Pilsen (urban wetland)

The park with wetlands, Lobezská jezírka, was built in the city of Pilsen as part of the Úslava river revitalisation (Fig. 4). This was mainly motivated by the city authorities' aim to reduce flood risk, and there was also an emphasis on citizens' well-being through the creation of a natural public area for recreation. Finally, the protection of nature and river landscapes was also an aim of the revitalisation. Before the park with four wetlands was established, there

Figure 3. Natural pond with wetland in Bratčice. Photo: Martina Sýkorová. Source: Macháč et al. (2023).

Figure 4. Wetlands Lobezská jezírka in Pilsen. Photo: Útvar koncepce a rozvoje města Plzeň. Source: Macháč and Louda (2019).

were unmaintained green areas with illegal dumps. Costs and benefits were assessed for the area of four wetlands with retention capacity and an adjacent park, where one of the wetlands is suitable for swimming and the smallest is used as a water playground for the youngest. As flood protection is one of the important ES in urban areas, the retention capacity of the wetlands in the case of floods is approximately 8,000 m^3 of water.

This case study is used to illustrate how the economic value of small-scale NBS can be captured when their multiple functions are considered together, including flood risk reduction, recreational use and enhancements to landscape aesthetics relative to the pre-intervention condition.

Case study Lödderitz Forest (large-scale floodplain)

The Lödderitz Forest case study represents a large-scale floodplain restoration in a rural landscape context, focusing on the reconnection of former floodplain areas to restore natural hydrological dynamics and associated ES (Fig. 5). The study area is located in the Middle Elbe floodplain, one of the largest remaining

hardwood floodplain forest complexes in Germany, characterised by high biodiversity and a wide range of floodplain-related ES (Scholz et al. 2012).

The restoration was implemented through a dike relocation completed in 2017, which reconnected approximately 600 hectares of former floodplain to the active floodplain. The intervention aimed to restore near-natural flooding regimes, improve habitat conditions for floodplain-typical species, and re-establish key regulating ES (Eichhorn et al. 2004). The measures included the construction of new flood protection infrastructure, adjustments to the existing drainage system, and technical measures to limit potential impacts on surrounding settlements.

The reconnection of the floodplain has significantly increased the inundation area and restored natural flood dynamics, contributing to improved flood retention capacity and a reduction of flood peaks in upstream river sections. The restored floodplain supports multiple ES (Scholz et al. 2012), including flood regulation, nutrient retention, biodiversity conservation, and climate regulation. Periodic inundation enhances the retention of nutrients and sediments, contributing to improved water quality in the river system.

The area also plays an important role in long-term climate regulation through the conservation of existing floodplain forests and the stabilisation of carbon stocks in biomass and soils. While additional carbon sequestration from new forest growth is limited due to the presence of mature forest stands, the restoration ensures the long-term protection and resilience of these carbon-rich ecosystems.

Overall, the Lödderitz Forest case study illustrates the multifunctional benefits of large-scale NBS in river floodplains, emphasising their role in flood risk reduction, ecosystem service provision, and landscape-scale climate adaptation.

The primary focus of this case study is to demonstrate how the benefits associated with improved water quality, particularly through nutrient retention (nitrogen and phosphorus), can be economically quantified and incorporated into decision-making processes.

Figure 5. Lödderitzer Forest first time directly inundated during the Elbe Winterflood 2023/2024. Photo: Michael Vieweg.

Identification of ecosystem services associated with the case study wetlands and floodplain

The identification of ES relevant to the implemented measures was based on a standardised methodological framework developed for the assessment of NBS in the context of climate change adaptation (Macháč et al. 2022). The methodology provides a structured approach for linking specific measures to the ES and additional benefits they generate.

For each case study, ES and related co-benefits were first identified through a qualitative, descriptive assessment reflecting the functional characteristics of the implemented measure and the local environmental context. The identification focused on ES that are directly or indirectly influenced by the measure and are relevant for its intended objectives, such as flood regulation, water quality improvement, climate regulation, biodiversity support, and recreational or aesthetic benefits.

Following the identification step, the relevance of individual services was evaluated using a semi-quantitative ordinal scale ranging from 0 to 3, reflecting their relative importance in terms of provision by the assessed measure (Fig. 6). A score of 0 indicates that the respective service or benefit is not provided by the measure. A score of 1 represents a low level of relevance or provision, a score of 2 indicates a medium level, and a score of 3 reflects a high level of relevance or provision for the given service or benefit.

The scoring was based on expert judgement supported by available project documentation and site-specific information. The resulting evaluation provides a qualitative overview of the ES associated with each measure and serves as a basis for the subsequent selection of ES for economic assessment.

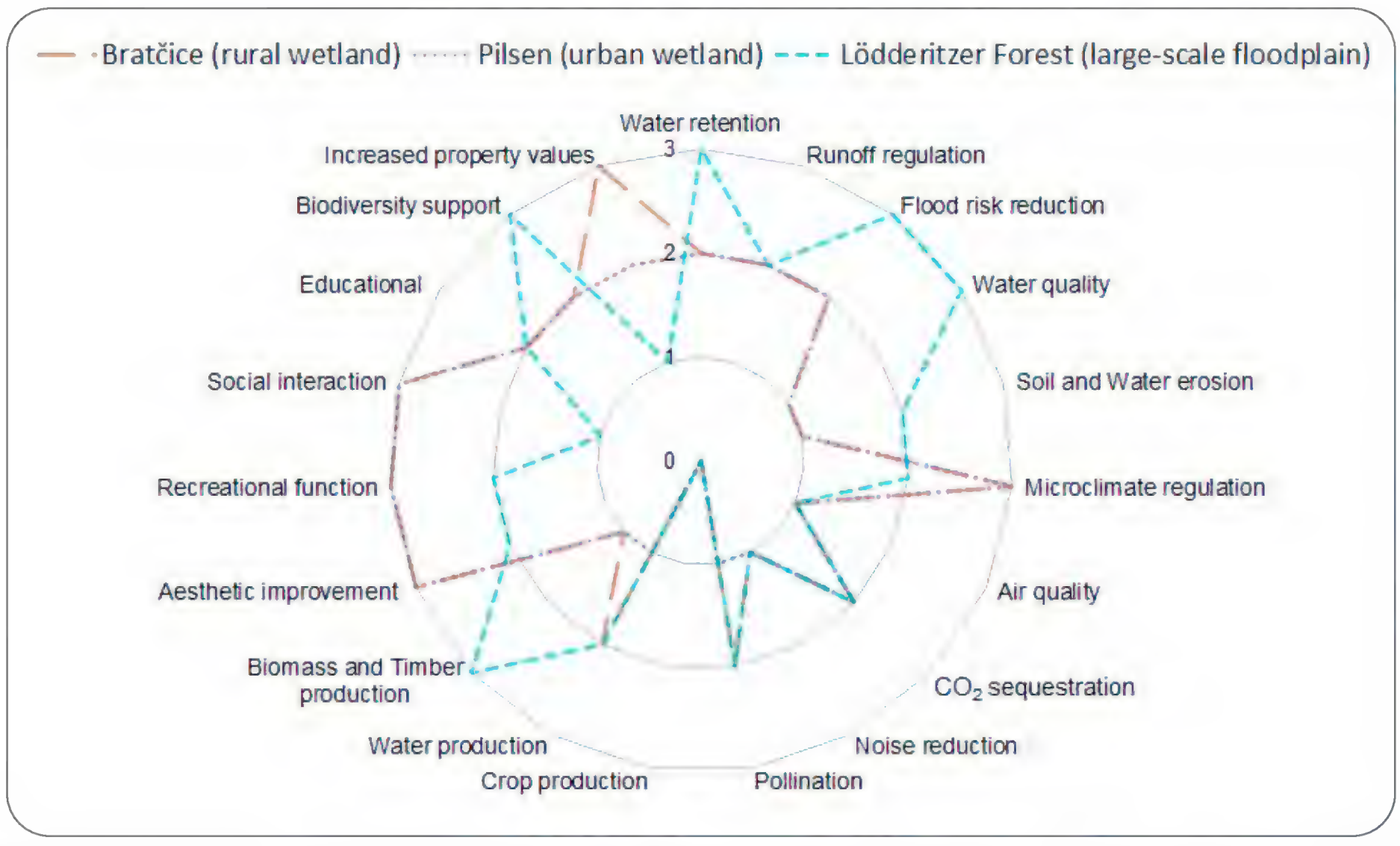

Figure 6. Qualitative assessment of ecosystem services across the three case studies. Legend: Ecosystem services were evaluated using an ordinal scale from 0 to 3, where 0 indicates that the service is not provided by the implemented measure, 1 indicates low relevance, 2 medium relevance, and 3 high relevance in terms of service provision. Source: authors.

CBA assumptions

CBA applied in this study follows a modified environmental CBA framework adapted to Central European conditions and methodologically builds on approaches previously developed and tested in similar contexts (Macháč et al. 2019; Hekrle et al. 2023). Investment and maintenance costs were identified ex post, based on consultations with the owners, operators, or entities responsible for the construction and long-term maintenance of the assessed measures. Where available, accounting data from completed projects were used; otherwise, costs were estimated in cooperation with practitioners directly involved in the implementation or maintenance of the case studies.

The benefits of the measures implemented in the case studies were translated into monetary terms using a combination of environmental economics valuation methods, selected according to the nature of each ecosystem service and data availability. These methods included the market price method, the substitute (avoided) cost method, and benefit transfer based on peer-reviewed studies. An overview of the ES included in the economic assessment, reflecting data availability for each case study, is provided in Table 2. The specific valuation approaches applied to individual ES and case studies are described in detail below.

Table 2. Overview of relevant ecosystem services included in the economic assessment for the case studies.

Ecosystem services	Bratčice	Pilsen	Lödderitzer Forest
Regulating			
Water retention	Included	Included	
Runoff regulation	Included		
Flood risk reduction		Included	
Water quality		Included	Included
Soil and Water erosion		Included	
Air quality	Included	Included	
CO_2 sequestration	Included		
Provisioning			
Water production	Included	Included	
Cultural			
Aesthetic improvement	Included	Included	
Recreational function	Included	Included	
Other benefits			
Biodiversity support		Included	
Increased property values	Included		

Source: own analysis.

Economic valuation approach for the Bratčice case study (rural wetland)

The economic assessment of the Bratčice case study focuses on the monetisation of the most relevant ES identified for the implemented measure. Valuation methods were selected individually for each ecosystem service, reflecting their specific characteristics, available data, and commonly applied approaches in

environmental economics. The assessment applies a combination of avoided cost approaches, market-based valuation, and proxy-based estimates to capture the key benefits provided by the restored pond and wetland system.

Runoff regulation benefits were monetised based on the rainwater retention capacity of the wetland system. An average retention rate of 80% was assumed for the Bratčice wetlands, reflecting their design and supported by empirical evidence on wetland hydrological performance, as well as consultations with the measure owners and designers. Precipitation data for the contributing catchment were used to estimate the volume of retained stormwater. The retained water was valued using market prices of wastewater treatment and rainwater collection infrastructure, representing avoided costs of treating water that would otherwise enter the sewer system.

Air-quality regulation benefits were assessed through the removal of key air pollutants (NO_2, SO_2, O_3, PM_{10}) and carbon sequestration. Pollutant removal rates were derived from published studies on the environmental performance of green infrastructure and wetland systems. These benefits were monetised using a combination of market prices of comparable mitigation measures and values reported in the literature (e.g. Macháč et al. 2019; Hekrle et al. 2023). Carbon sequestration was valued using market prices of CO_2 equivalents under the EU Emissions Trading System (EU ETS), following published price data.

Aesthetic benefits were monetised through estimated property value uplift associated with proximity to the revitalised water body. Based on empirical evidence from hedonic pricing studies, a 3% increase in property values within the wider surrounding area and a 5% increase for directly adjacent properties were assumed. Local market prices of residential properties were used to express these effects in monetary terms.

Additional benefits include savings in irrigation costs, as water retained in the wetland is reused for irrigating nearby greenery. This benefit was valued based on the volume of reused water and the market price of potable water that would otherwise be required. Recreational benefits were also considered, reflecting the use of the area as a leisure space for residents. Visitor numbers during the main use period were estimated, and the entrance fee to a comparable children's leisure facility in the nearest city was used as a proxy for visitors' willingness to pay.

Economic valuation approach for the Pilsen case study (urban wetland)

The economic assessment of the Pilsen case study was based on a benefit transfer approach using value function transfer derived from meta-analytical studies. Two separate valuation components were applied to reflect the multifunctional character of the nature-based solution: (i) benefits associated with the restored ponds and wetlands and (ii) benefits related to the adjacent park greenery and recreational infrastructure.

Benefits associated with the ponds and wetland system were estimated using a meta-analytic value function originally developed by Brander et al. (2006) and subsequently extended by EFTEC (2010). This framework synthesises results from several hundred primary valuation studies and links wetland benefits to key biophysical and socio-economic characteristics, such as wetland type and size, population density, income levels, availability of substitute sites, and

the provision of ES. The valuation focused on ES relevant to the local context, including flood regulation, water quality improvement, and recreational and aesthetic benefits, while services such as commercial and recreational fishing were excluded due to their limited relevance for the site. Local characteristics of the Lobezská jezírka, including wetland area and regional socio-economic indicators, were used to parameterise the value function.

In line with recommendations by Brander et al. (2010), both average and marginal values were considered to account for the relatively small scale of the intervention and changes in ecosystem service provision. The final value applied in the CBA was derived as a representative estimate reflecting the range of plausible benefit values and ensuring consistency with values reported for wetlands in the Czech Republic.

Benefits associated with the adjacent park area and recreational features were assessed using a second benefit transfer based on the meta-analysis by Patrick and Randall (2013), which focuses on the valuation of urban and peri-urban green spaces. This meta-analytic function relates recreational, aesthetic, biodiversity-related, and other benefits of green areas to site-specific characteristics such as park size, location within the urban structure, income levels, and the valuation method used in primary studies. Local conditions of the park area were used to specify the function and estimate the aggregate annual benefits associated with recreational and amenity functions.

Economic valuation approach for the Lödderitz Forest case study (large-scale floodplain)

The economic assessment of the Lödderitz Forest case study addresses a large-scale floodplain restoration characterised by complex hydrological processes and a wide range of interacting ES. Many of the benefits associated with dike relocation, such as biodiversity enhancement, habitat restoration, and long-term landscape resilience, are difficult to express in monetary terms and are therefore described qualitatively. Quantitative economic valuation is feasible primarily for ES that can be directly linked to hydrological processes and model-based evidence.

The relocation of the dike restored near-natural flooding dynamics over a large floodplain area, leading to improved flood retention and the attenuation of flood peaks in upstream river sections. Evidence from hydrological and flood modelling indicates that dike relocation can reduce floodwater levels during extreme events and significantly increase inundation areas, thereby contributing to improved flood protection at the regional scale (Scholz et al. 2012; Promny et al. 2014; Heinzelmann et al. 2016; Otte-Witte 2018). These effects, however, depend on flood magnitude and spatial context and require detailed hydraulic modelling to be translated into economic terms. As such, flood protection benefits were not monetised directly within this study but are acknowledged as an important co-benefit of the measure.

The economic valuation therefore focused on water quality regulation, specifically nutrient retention (nitrogen and phosphorus), which can be robustly quantified under inundation conditions. Following dike relocation, the reconnection of approximately 600 hectares of former floodplain significantly enhanced nutrient retention capacity during flood events (Scholz et al. 2012). The valuation of this ecosystem service was based on an avoided cost approach,

linking retained nutrient loads to the costs of alternative measures required to achieve equivalent reductions, such as agricultural management strategies aimed at reducing fertiliser application (Mewes 2006; Born et al. 2012).

Estimated nutrient retention was combined with unit cost estimates for nutrient abatement to derive the annual value of the floodplain's water purification function. This approach reflects the role of restored floodplains as natural nutrient sinks and provides a conservative, evidence-based estimate of economic benefits that can be directly attributed to the implemented measure.

Calculation of net present value

To address the temporal mismatch between costs and benefits, all cost and benefit flows were converted into present values (PV) using a fixed discount rate of 4%, in line with the European Commission's guidance for project appraisal (European Commission 2015). Cost–benefit analyses were conducted for 25-year and 50-year time horizons, with the 50-year horizon reflecting the expected technical and functional lifespan of wetland measures. Economic performance was evaluated using cumulative present values, net present value (NPV), and the payback period.

To ensure internal consistency and comparability across case studies, all costs and benefits were expressed in real terms and harmonised to constant prices of the year 2022 in euros (EUR). Where necessary, original values were converted using appropriate inflation indices and exchange rates prior to discounting.

To assess the robustness of the results, a scenario-based sensitivity analysis was conducted with a focus on the choice of the discount rate. Alternative discount-rate scenarios were applied to reflect uncertainty in long-term social time preference, and their effects on key economic indicators were examined. The sensitivity analysis evaluates how variations in the discount rate influence NPV, BCR, and the payback period, thereby providing insight into the stability of the economic performance of the assessed measures under different discounting assumptions.

Results

Costs of the assessed wetlands and floodplain

The cost side of the CBA covers both investment and maintenance costs associated with the implementation of the assessed NBS. Investment costs reflect the one-off expenditures required for the construction and establishment of the measures, while maintenance costs represent recurring expenditures necessary to ensure their long-term functionality. An overview of the original cost estimates and their conversion to constant prices of 2022 in euros (EUR) is provided in Table 3.

In the Bratčice rural case study, investment costs include sediment removal from the former fire-fighting reservoir, bank stabilisation and revitalisation, planting of greenery, and the installation of an irrigation system comprising an accumulation tank, pump, and water distribution infrastructure. In addition to investment costs, regular maintenance costs were considered, including greenery maintenance, operation of the irrigation system, staff costs, and maintenance of leisure infrastructure elements.

Table 3. Investment and maintenance costs of the assessed case studies (original values and prices adjusted to 2022 EUR).

Case study	Investment costs	Maintenance costs (annual)	Present value of total costs (in EUR, constant prices of 2022) in 25 years
Bratčice (rural wetland) (original prices of 2022)	11,500,000 CZK	55,000 CZK	502,737 EUR
Pilsen (urban wetland) (original prices of 2014)	14,205,426 CZK	500,0000 CZK	1,320,463 EUR
Lödderitzer Forest (large-scale floodplain) (original prices of 2015)	23,200,000 EUR	not relevant	26,931,720 EUR

Source: own analysis.

For the Pilsen (Lobezská jezírka) urban case study, investment costs comprise the construction of four wetlands, associated park infrastructure, and related technical elements. Maintenance costs were estimated on a per-square-metre basis and include routine wetland maintenance, sediment removal, and upkeep of greenery and recreational facilities.

The Lödderitz Forest case study represents a large-scale floodplain restoration project, where investment costs are dominated by the relocation of the dike, including new dike construction, adaptation of the drainage system, and construction of a pumping station (Dehnhardt et al. 2015). Maintenance costs were not explicitly included in the CBA, as the measure does not lead to a substantial increase in long-term maintenance expenditures compared to the pre-intervention situation.

Benefits of the assessed measures

Bratčice case (rural wetland)

The quantified benefits reflect the multifunctional character of the semi-natural pond and wetland system. The dominant monetised benefit is stormwater retention, with approximately 89% of runoff from surrounding rooftops and paved surfaces retained and treated through a pre-treatment wetland, contributing to water quality improvement and protection against intense rainfall events. Additional quantified benefits include microclimate regulation, air quality improvement, carbon storage, savings in irrigation water use, recreational and amenity benefits, and associated increases in nearby property values. Biodiversity and social benefits were identified but not monetised.

Pilsen case (urban wetland)

The quantified benefits in the Pilsen case study are associated with a broad range of ES provided by the wetlands and the adjacent park area. Monetised benefits include stormwater regulation and retention, microclimate regulation, air quality improvement, carbon storage, biomass-related provisioning services, and cultural ES related to recreation and aesthetics. Social and educational benefits and biodiversity enhancement were identified but not fully monetised.

Lödderitz Forest case (large-scale floodplain)

In the Lödderitz Forest case study, quantified benefits are limited to water quality regulation, specifically nutrient retention (nitrogen and phosphorus) in the restored floodplain. Nutrient retention benefits were monetised using an avoided

cost approach based on alternative nutrient abatement measures. Other benefits related to flood protection, biodiversity enhancement, and landscape resilience were identified but are presented qualitatively.

An overview of the ES included in the economic assessment for each case study is provided in Table 2, while the calculated benefit values for the 25- and 50-year time horizons are summarised in Table 4.

Table 4. Results of the cost–benefit analysis for the assessed case studies (present values, 2022 EUR).

Case study	Time horizon (years)	Cumulative present value of costs (EUR)	Cumulative present value of benefits (EUR)	Net present value (EUR)	Payback time (years)
Bratčice (rural wetland)	25	502,737	562,343	59,606	15
	50	515,857	647,141	131,284	
Pilsen (urban wetland)	25	1,320,463	14,212,362	12,891,899	1
	50	1,612,292	19,543,657	17,931,365	
Lödderitz Forest (large-scale floodplain)	25	26,931,720	12,694,424	-14 237,296	>50
	50	26,931,720	17,456,316	-9,475,404	

Source: own analysis.

It should be emphasised that the valuation of most benefits in the Pilsen case study is based on benefit transfer from existing meta-analyses and literature sources rather than on primary local measurements. The resulting benefit estimates therefore represent model-based approximations rather than empirically observed local effects. While this approach is consistent with standard practice in applied ecosystem service valuation, it introduces additional uncertainty related to transfer errors, contextual differences, and scaling assumptions. Consequently, the absolute magnitude of the monetised benefits should be interpreted with caution, and the results should be understood primarily as indicative of the order of magnitude and relative economic relevance of the wetlands rather than as precise site-specific values.

Results of cost-benefit analysis

For the Bratčice case study, the cumulative present value of monetised benefits reaches EUR 562,343 after 25 years and EUR 647,141 after 50 years. The resulting net present value is positive under both time horizons, amounting to EUR 59,606 after 25 years and EUR 131,284 after 50 years. The payback period is 15 years, indicating that monetised benefits exceed discounted costs within the assessed time horizon.

In the Pilsen case study, the cumulative present value of monetised benefits amounts to EUR 14,212,362 after 25 years and EUR 19,543,657 after 50 years. Corresponding net present values are strongly positive, reaching EUR 12,891,899 for the 25-year horizon and EUR 17,931,365 for the 50-year horizon. The payback period is 1 year, reflecting the rapid accumulation of monetised benefits.

For the Lödderitz Forest case study, the cumulative present value of monetised benefits reaches EUR 12,694,424 after 25 years and EUR 17,456,316 after 50 years. Despite increasing benefit values over time, the net present value remains negative under both horizons, amounting to EUR −14,237,296 after 25 years and EUR −9,475,404 after 50 years. A payback period is therefore not achieved within

the assessed time horizons. These results reflect the deliberately conservative scope of the monetary assessment, as only one benefit category (water quality regulation through nutrient retention) was monetised. This single benefit already represents a substantial share (48–65%) of total investment costs, and the inclusion of additional major benefits, particularly those related to flood risk reduction, would be expected to substantially increase the overall net benefits.

Sensitivity analysis

A scenario-based sensitivity analysis was conducted to examine the influence of the discount rate on the economic results, using alternative rates of 2% and 6% in addition to the baseline rate of 4%. The results confirm that the choice of discount rate has a noticeable effect on the magnitude of monetised benefits and net present values, while the overall ranking and qualitative conclusions across case studies remain unchanged.

In the Bratčice case study, net present values remain positive under both alternative discount rates and time horizons. At a discount rate of 2%, the net present value reaches EUR 94,247 after 25 years and EUR 216,574 after 50 years, reflecting the stronger weighting of long-term benefits. At 6%, net present values decrease to EUR 29,549 after 25 years and EUR 60,240 after 50 years, indicating higher sensitivity to discounting but still confirming positive net benefits. The payback period is shortened at lower discount rates and extended by approximately one year at higher discount rates.

For the Pilsen case study, the results are robust across all tested scenarios. Net present values remain strongly positive regardless of the discount rate, reaching EUR 16.27 million after 25 years and EUR 26.51 million after 50 years at 2%, and EUR 10.44 million after 25 years and EUR 13.00 million after 50 years at 6%. These results indicate low sensitivity of the overall economic performance to discount rate assumptions due to the high level of monetised benefits.

In the Lödderitz Forest case study, net present values remain negative under all tested discount rates and time horizons. At a lower discount rate of 2%, net present values improve substantially, reaching EUR −1.20 million after 25 years and EUR −1.40 million after 50 years, but do not turn positive. At 6%, higher discounting further reduces the present value of benefits, resulting in net present values of EUR −14.25 million after 25 years and EUR −12.17 million after 50 years. These results reflect the conservative scope of monetisation in this case study and the strong dependence of long-term benefits on discounting assumptions.

Overall, the sensitivity analysis confirms that while discount rate assumptions influence the magnitude of economic indicators, they do not alter the main conclusions of the CBA regarding the relative economic performance of the assessed measures.

Discussion

The results indicate that wetlands can deliver economically relevant benefits when assessed as NBS, particularly in relation to water retention, flood mitigation, and regulating ES. This finding is in line with broader conceptual and applied literature on NBS, which emphasises their potential to address multiple societal challenges simultaneously, including climate adaptation, water

management, and risk reduction (Kabisch et al. 2016; Keesstra et al. 2018; Albert et al. 2019). Empirical studies further demonstrate that NBS can be economically competitive with grey or hybrid alternatives, although their performance strongly depends on local environmental, institutional, and policy contexts (García-Herrero et al. 2022; Scholz 2022; Chelli et al. 2025).

At the same time, the results confirm that the economic outcomes of wetland restoration are highly context-dependent and sensitive to assumptions regarding biophysical processes, land-use characteristics, and valuation parameters. Similar limitations have been identified in ecosystem service-based assessments, where the transferability of results across sites is constrained by ecological heterogeneity and scale effects (Ghaley et al. 2014; Greenhalgh et al. 2017; Valencia Cotera et al. 2023). This sensitivity reinforces earlier critiques of CBA, which highlight that aggregated monetary indicators may mask underlying variability and uncertainty when used to inform policy decisions (Vejchodská 2015; Dennig 2018; Dehnhardt et al. 2022).

The analysis also highlights fundamental limits of monetisation in the evaluation of wetlands as NBS. While CBA enables comparison across alternative measures using a common monetary metric, a substantial share of ecosystem service benefits cannot be robustly expressed in monetary terms. Conceptual and empirical research on ES stresses that cultural, social, and relational values, as well as long-term ecological functions, are frequently underrepresented or excluded from monetary valuation frameworks (Ainscough et al. 2019; Saarikoski et al. 2022; Viti et al. 2022). As a result, monetary estimates should be interpreted as partial representations of value rather than comprehensive measures of societal welfare (Boda 2018; Masur and Posner 2018).

It is critical to interpret the CBA results within the context of the methodological selectivity inherent in CBA applied to NBS. A common criticism of CBA in the field of NBS is that it does not provide a comprehensive absolute evaluation but rather an indication of partial anthropogenic benefits (Markanday et al. 2024; Chelli et al. 2025; Costadone and Zhang 2025). Evaluators often face a lack of biophysical data or methodological complexity when attempting to assign monetary values to key services such as biodiversity support, microclimate regulation, or long-term health improvements. Consequently, these services are frequently omitted from the final NPV calculation or are only mentioned qualitatively (Tal-maon et al. 2024; Vicuña et al. 2025). The present assessment does not provide an absolute or exhaustive valuation of wetlands; instead, it serves as an indication of specific, quantifiable anthropogenic benefits. Similar to findings reported for green roofs (Dennig 2018; Bolinches et al. 2020; Dehnhardt et al. 2022), the CBA applied here is constrained by a “measurability trap”, whereby only those ESs for which reliable biophysical data and established valuation methods exist are included in the final monetary calculation.

Specifically, while the model accounts for tangible benefits such as water retention and flood mitigation, it omits several critical services due to data scarcity or methodological complexity. Key functions such as biodiversity support, long-term health and well-being improvements, and microclimate regulation, which are often primary ecological drivers of wetland restoration, remain unmonetised in this study. Because these non-market benefits are excluded, the resulting NPV and BCR should be viewed as conservative lower-bound estimates of the project’s true worth to society.

Uncertainty represents a further key dimension shaping the interpretation of valuation results. Monetary estimates are affected by uncertainties related to biophysical modelling, benefit transfer, discount rates, and assumptions about future environmental change. In particular, as noted by A. Sharbaf and Schneider-Marin (2025) and Hekrle et al. (2023), the choice of the discount rate is a key uncertain variable that can substantially affect the outcome of economic evaluations. Methodological literature on CBA and climate adaptation highlights that such uncertainties are not merely technical but reflect normative choices embedded in analytical frameworks, including the definition of system boundaries and acceptable levels of risk (Dennig 2018; Bolinches et al. 2020; Dehnhardt et al. 2022). This supports the view that CBA should be understood as a decision-support tool rather than a deterministic decision rule for NBS.

Beyond methodological considerations, the findings also resonate with governance-oriented perspectives on barriers to NBS implementation. Even where economic assessments indicate positive net benefits, implementation may remain limited due to structural and institutional constraints. A growing body of literature identifies fragmented incentives, transaction costs, administrative complexity, and limited institutional capacity as persistent barriers across rural and urban contexts (Sarabi et al. 2020; Solheim et al. 2021; Martin et al. 2025). Empirical studies focusing on farmers and landowners further show that attitudes towards NBS are shaped not only by economic incentives but also by motivational drivers, opportunity costs, and perceptions of fairness and autonomy (Baur et al. 2016; van Dijk et al. 2016; Meierová and Chvátalová 2022; Zaňková et al. 2025).

These findings point to the importance of distributional and justice-related aspects in the appraisal of wetlands as NBS. While benefits such as flood protection or climate regulation accrue broadly to society, costs are often borne locally through land-use restrictions, foregone income, or increased management responsibilities. Such asymmetries have been identified as key obstacles to implementation, particularly on privately owned land (Slavíková and Raška 2019; Anderson et al. 2022; Potočki et al. 2022). Addressing these distributional issues requires policy instruments that go beyond information provision and explicitly engage with incentive structures and governance arrangements (Calliari et al. 2022; Chen et al. 2023).

Overall, the results support calls for a more pluralistic and integrated appraisal of wetlands as NBS (see Wantzen and Cao 2026). While CBA based on ES offers a transparent and policy-relevant framework for highlighting selected economic benefits, reliance on monetisation alone risks overlooking non-monetary values, distributional effects, and institutional constraints that are central to implementation (Ainscough et al. 2019; Albert et al. 2019; Nelson et al. 2020). Combining economic assessment with ecosystem service frameworks, governance analysis, and stakeholder perspectives therefore appears essential for a more comprehensive and policy-relevant evaluation of NBS (see Stammel et al. 2026).

Conclusion

The implementation of NBS is affected by a number of barriers, of which a lack of awareness of the benefits is one of the most significant. This lack of awareness leads to limited support for the measures from various stakeholders. At the same time, implementation is shaped by broader institutional conditions, such as administrative complexity, limited local capacity, and entrenched pref-

erences for conventional “grey” approaches, which can impede uptake even when societal benefits are substantial.

The article focused on presenting the possibilities of assessing impacts using CBA and the concept of ES, which can be used for both decision-making and the communication of measures. Although monetising all benefits and costs remains challenging and the methods are associated with several uncertainties, the results of the case studies consistently indicate positive net socio-economic outcomes. In particular, constructed wetlands and floodplain revitalisation can be considered beneficial from a societal perspective across the assessed contexts. The case studies also illustrate how the relative importance of individual ES can vary considerably depending on the environment in which the measure is implemented. While the results of the two Czech case studies indicate positive net benefits from a societal perspective, they do not imply an even distribution of costs and benefits among stakeholders. In practice, the implementation costs and opportunity costs of NBS are often borne by specific actors, whereas many benefits accrue more broadly and over longer time horizons, which has important implications for policy design and acceptance. Therefore, CBA results should be communicated together with a clear statement of key assumptions and uncertainties and interpreted alongside a simple distributional perspective (“who pays, who benefits”), especially where local acceptance is critical.

Although attempts to monetise benefits are often criticised due to various uncertainties, abandoning this approach is not advisable. Instead, continued development of valuation methods and systematic data collection are needed to enable more robust quantification of individual ES based on a clearer definition of their provision. Without clear and easily graspable evidence of costs and benefits, it is difficult to convince stakeholders to implement NBS in different contexts, whether in urban areas, agricultural landscapes, or larger river–floodplain systems.

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Conflict of interest

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Ethical statement

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All literature review, analytical procedures, data processing, interpretation of results, and scientific conclusions were carried out exclusively by the authors. The AI tool did not generate original data, perform statistical analyses, or influence methodological decisions. The authors carefully reviewed, edited, and verified all AI-assisted content and take full responsibility for the final manuscript.

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Author contributions

Jan Macháč: Conceptualization; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Supervision; Validation; Writing – original draft; Writing – review and editing. Lenka Zaňková: onceptualization; Visualization; Writing – original draft; Writing – review and editing. Marek Hekrle: Data curation; Conceptualization; Formal analysis; Investigation; Writing – original draft; Writing – review and editing. Mathias Scholz: Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Writing – original draft.

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Data availability

All of the data that support the findings of this study are available in the main text.

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